Use of the Automatic Identification System (AIS) on Autonomous Weather Buoys for Maritime Domain Awareness Applications

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Abstract- **The United States Coast Guard (USCG), as part of the Department of Homeland Security, is responsible for a wide variety of missions in the maritime domain. In order to support the accomplishment of these missions, the USCG needs to collect as much information as possible on activities occurring in the maritime domain. A large part of maritime activity relates to the movement of vessels. Therefore, detection, classification, identification and monitoring of vessels are a key component of what is known as Maritime Domain Awareness (MDA).**

The Automatic Identification System (AIS) is a technology that is used primarily as a tool for maritime safety, including vessel collision avoidance and as a means for coastal nations' Vessel Traffic Services (VTSs) to get information on vessels operating near their coasts. AIS equipment aboard vessels continuously and autonomously transmits information about the vessel including its identity, position, course, and speed to enhance safety. These transmissions can be received by other vessels or by land-based stations equipped with AIS receivers. The USCG sees the capability AIS provides, particularly for vessel tracking, as a major contributor to MDA and VTS. To extend the capability of USCG land-based AIS monitoring stations further offshore, the USCG Maritime Domain Awareness Program Integration Office sponsored the development of a near real-time, autonomous automatic identification and telemetry system based on AIS technology for installation on National Oceanic and Atmospheric Administration (NOAA) weather buoys through the National Data Buoy Center (NDBC) and its technical support contractor, Science Applications International Corporation (SAIC).

This paper discusses system design of a prototype, autonomous, buoy-based, embedded system for AIS-equipped vessel detection using an AIS receiver and satellite transmitter for near real-time relay of vessel identification data. This paper also describes follow-on enhancements to the system to further extend AIS coverage and field testing of the system. The prototype system development began in August 2004. The prototype system receives AIS data from AIS-equipped vessels on a timed, periodic schedule, processes and verifies received data onboard the buoy, and relays these data from the remote weather buoy via satellite in near real-time to the NDBC Data Assembly Center (NDAC), and then on to the USCG. The prototype system was successfully field tested March 2005 through June 2005 on four near-shore NDBC buoys located in the Strait of Juan de Fuca, near San Francisco Harbor, near Charleston, South Carolina and near Cape Cod, Massachusetts. Field testing successfully proved the concept of collecting vessel identification data from an autonomous AIS system on NDBC weather buoys. Enhancements to the system were developed from August 2005 to February 2006. These enhancements extend AIS monitoring coverage from periodic AIS monitoring to continuous monitoring and conserve system power by insertion of NDBC weather data into the AIS data stream returning it to NDBC using the low power satellite telemetry of the AIS system rather than the existing high power geosynchronous satellite transmission system in use on most NDBC weather buoys. Extended field testing of the enhanced AIS system on four deep ocean NDBC weather buoys began in March 2006 and will continue through February 2007.

The installation of an AIS system on NDBC weather buoys provides additional platforms for the use of AIS by the USCG in support of all national maritime missions. The system also provides an opportunity for NDBC to increase the temporal sampling of environmental data from buoys with the system installed as a result of the increased bandwidth available using the satellite transmitter that is part of the buoy-based AIS system and and to broadcast weather data directly to nearby vessels using the AIS. Efforts presently underway through the International Electrotechnical Commission (IEC) to develop standards for real-time broadcast of environmental data over AIS marine bands to vessels using an environmental data message standard under development by the International Maritime Organization (IMO) presents NOAA/NDBC with the opportunity to provide real-time environmental data directly to passing vessels in the near future.

I. Introduction

This paper describes the development and testing of a low power, Automatic Identification System (AIS) for use on autonomous weather buoys operated by the National Oceanic and Atmospheric Administration (NOAA), National Data Buoy Center (NDBC). The development and integration of this system, which was deployed and tested on four NOAA weather buoys, was sponsored by the USCG, Maritime Domain

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Awareness Program Integration Office. An overview of the role of AIS in support of Maritime Domain Awareness will be discussed. An overview of the buoy AIS system design is presented, which includes buoy embedded system architecture and satellite data transmission system, data filtering and processing on the buoy, and the shore-side processing and data distribution system. System testing and results to date are then presented and future long-term testing and evaluation of the system is discussed.

II. AUTOMATIC IDENTIFICATION SYSTEM DESCRIPTION

A. Overview of AIS

The Automatic Identification System (AIS) is a system used by vessels at sea primarily for identification of and exchange of information with other vessels as an aid in collision avoidance. The International Maritime Organization (IMO) adopted performance standards for AIS in 1998 and set out the following intended uses of AIS:

> *"1.2 The AIS should improve the safety of navigation by assisting in the efficient navigation of ships, protection of the environment, and operation of Vessel Traffic Services (VTS), by satisfying the following functional requirements:*
> *.1 in a ship-to-ship mode for collision avoidance;*
> *.2 as a means for littoral States to obtain information about a ship and its cargo; and*
> *.3 as a VTS tool, i.e. ship-to-shore (traffic management)*[1]*."*

AIS is very useful in identifying vessels observed by other means (e.g., visually or by radar) and is particularly helpful in detecting vessels not able to be detected by usual means (e.g., at night, in fog, in radar blind areas, etc.). AIS provides a means for these vessels to exchange identification, position, course, speed and other data with all other nearby AIS-equipped vessels and shore stations.

AIS compiles shipboard sensor data (e.g., position from GPS, heading from gyrocompass, etc.) with ship static and voyage related data into messages that are autonomously broadcast and received by VHF-FM radios incorporated into the AIS transceiver. In order to ensure that messages sent by AIS equipment operating in close proximity don't interfere with each other, AIS equipment self-organizes its broadcasts using the Self-Organizing Time Division Multiple Access (SOTDMA) protocol. A minute of time is divided into 2250 slots. Information contained in an AIS message is transmitted during one or more of these slots. The AIS unit automatically and autonomously determines what slots are available for its use, broadcasts its intentions for slot use to other units to allocate the slots, and transmits its messages. SOTDMA sets AIS apart from other systems that rely upon receiving a shore-side 'trigger' to make the system broadcast (i.e., a transponder) or are set to a fixed broadcast schedule - both are unable to mitigate multiple units from attempting to transmit at the same time.

Information transmitted by AIS equipment consists of dynamic, static and voyage related information [2]. Dynamic information, such as vessel heading, course, speed, position, etc., is broadcast in near real-time depending on vessels' speed and heading change. Static information (vessel identity, dimensions, etc.) is transmitted every 6 minutes as is voyage related data such as vessel destination, hazardous nature of its cargo, etc.

B. AIS Role in Maritime Domain Awareness

Maritime Domain Awareness, or MDA, is: "*The effective understanding of anything associated with the global maritime environment that could affect the security, safety, economy, or environment of the United States.* [3]" Simply stated, MDA is understanding what's going on out on the water. Not surprisingly, vessel tracking – detecting, classifying, identifying and tracking ships – is critical to MDA. While MDA primarily supports maritime security, its applicability goes far beyond that to support all national maritime missions and interests. Traditional USCG missions such as Maritime Safety, Search and Rescue (SAR), Vessel Traffic Management and Law Enforcement are all served by MDA, and other federal agencies with maritime interests are supported. For example, the USCG is currently working with the National Oceanic and Atmospheric Administration (NOAA) to use AIS in support of protection of endangered living marine resources. The primary use of AIS for MDA will be the reception of AIS data transmitted from AIS-equipped vessels for the purpose of tracking their movements. The data collected will be disseminated to other systems in support of maritime safety, security, environmental protection, law enforcement and other missions.

C. USCG AIS Capability

The USCG currently has extensive AIS capability through the Ports and Waterways Safety System (PAWSS) acquisition project and is acquiring full AIS capability throughout the U.S. maritime domain through a major acquisition called Nationwide AIS. Below are brief descriptions of some of the existing USCG AIS capability:

USCG Research and Development Center AIS Efforts. The USCG Research and Development (R&D) Center in Groton, CT has been a leader in the development of AIS technology, standards, and assessment of AIS capabilities. The R&D Center has deployed many AIS receivers around the U.S. coastline and is performing detailed performance analysis of AIS installations on a wide variety of platforms, investigating AIS network and distribution methods and a variety of prototype system development efforts.

AIS at Vessel Traffic Services. By the end of 2004, when the initial AIS carriage regulations came into force, AIS capability was deployed at all USCG VTS areas. VTSs are USCG units that manage vessel traffic and provide navigation assistance to vessels somewhat analogous to air traffic control for aircraft.

PAWSS and its AIS capability at VTSs has greatly improved the ability to monitor vessel traffic in the busiest U.S. ports.

AIS on Offshore Platforms. AIS equipment has been placed on four existing offshore platforms used for petroleum production in the Gulf of Mexico. These platforms are communications sites operated by PETROCOM, a provider of cellular communications services. The data is sent to the USCG from the platforms using their existing communications infrastructure. This effort has been successful in extending the range of VTS Houston/Galveston and AIS tracking in the Gulf of Mexico.

Most AIS efforts in place by the USCG are land-based (AIS at VTSs, R&D Center efforts, AIS at other command and control centers) and thus are limited to the line of sight propagation of the AIS VHF-FM signals, generally about 40 nm offshore (coverage is very dependent on antenna height, ambient radio noise, tropospheric factors, etc.). In order to detect and identify vessels further offshore, other platforms were considered as potential for placement of AIS receivers. The existing array of buoys established and maintained by NOAA's NDBC were an obvious choice as an offshore platform of opportunity. They were in ideal locations, many more than 40nm offshore, already had complex data collection and communications equipment integrated into them, and had proven resiliency. The NDBC and USCG have worked together for many years in the design, deployment, and maintenance of these buoys, so a partnership to leverage them as platforms for AIS was a natural choice.

III. NDBC Buoy AIS System

A. System Overview

The National Data Buoy Center operates a network of 98 environmental measurement buoys that surrounds the continental United States coasts, Alaska south of the Bering Strait, and the Hawaiian Islands. In an effort to expand the coverage of its AIS network farther offshore, the USCG sponsored a project to install embedded AIS receiver systems on four NDBC buoys to test the viability of receiving AIS data further offshore from these platforms. Four buoys were deployed with an NDBC-developed system that integrated a low-power, commercial AIS receiver, a microcontroller-based AIS Control Unit, and IRIDIUM satellite modem for near real-time data transmission of AIS data in early 2005 for proof-of-concept testing. Fig. 1 is a block diagram of the AIS system developed by NDBC for the USCG. The proof-of-concept system was successfully tested for a 60-day period. A modified system was then deployed on four deep ocean NDBC buoys beginning in late spring 2006 for extended testing. This second system deployment implemented design and firmware changes to: increase AIS receiver coverage time at the buoys to 24 hours a day, 7 days a week; reduce power consumption by the embedded buoy system; transmit environmental data acquired by sensors on the buoy with the AIS data by IRIDIUM satellite; and interface the embedded AIS system

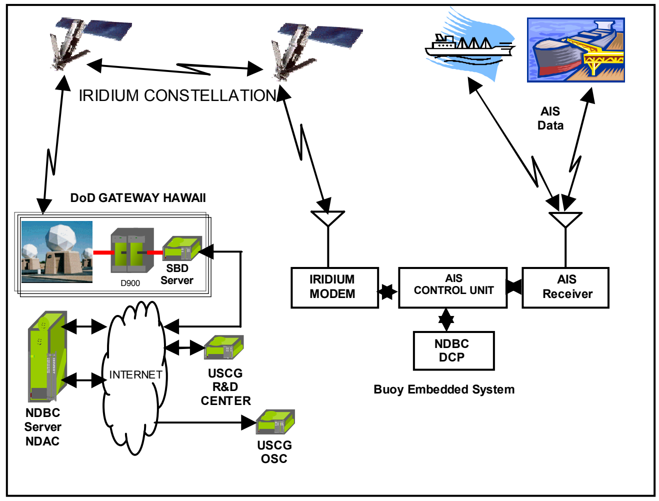

Figure 1. Block Diagram of Buoy AIS system

with the buoy renewable power system. AIS data and NDBC environmental data are transmitted from these buoys by IRIDIUM satellite Short Burst Data (SBD) messages through the Department of Defense (DoD) secure IRIDIUM gateway in Hawaii, and from there to the NDAC, where the NDBC data is extracted and the AIS data are validated and transferred to the USCG by internet.

B. Buoy Embedded System Architecture

AIS data collection from NDBC buoys is performed by an autonomous, embedded system separate from the buoy's electronic systems with the exception of connections to the buoy power system and a serial connection to the NDBC environmental Data Collection Platform (DCP) for acquisition of the buoy environmental data that is transmitted with AIS data packets. The AIS embedded system is shown in the lower right of Fig 1.

The embedded AIS system consists of a very low power AIS receiver, an AIS Control Unit (ACU), and an IRIDIUM satellite data modem. The AIS receiver is a commercially available, receive-only unit capable of receiving all ITU-R M.1371-1 AIS messages on the AIS VHF data link (VDL) and outputting these VDL messages (VDMs), that contain vessel identification and voyage-related data, over a RS-232 presentation interface to the ACU.

System functions are controlled and monitored by the ACU, which is a NDBC-developed single-board computer based on a low power 68332 microprocessor. The ACU receives AIS data continuously from the AIS receiver, filters these data sending back only the most recent AIS message, relative to IRIDIUM transmission time, of each type from each unique vessel. The ACU also formats AIS data into IRIDIUM SBD packets, sets up and controls SBD data transmissions by the IRIDIUM satellite modem, and provides power management of all AIS system components.

The IRIDIUM satellite modem is a commercially available IRIDIUM data modem that transmits AIS message packets to the NDAC every ten minutes.

The buoy embedded system is capable of receiving Mobile-terminated, SBD messages originated by NDBC that reconfigure the system and allow different operating scenarios of the AIS system. The system can be configured for more- or less-frequent IRIDIUM data transmissions, with the minimum transmit duty cycle limited only by the minimum time required to initiate and complete an IRIDIUM SBD transmission. Data from the AIS receiver is continuously received and filtered by the ACU concurrently while data is transmitted by IRIDIUM SBD.

The ACU is also capable of being remotely commanded by SBD message to receive an incoming data call to the IRIDIUM modem using IRIDIUM circuit-switched calling. This allows a remote operator to connect to the buoy system as though connected by a laptop locally for extended diagnostics and configuration of the system. In addition, the system can pass through commands to the NDBC DCP allowing remote re-configuration and diagnostics of the DCP by way of the ACU.

C. Land-based Architecture

AIS data are received as SBD Packets at the NDAC from the DoD secure IRIDIUM gateway by direct Internet Protocol (IP) as they are transmitted from the buoy. These data are logged and quality checked for any transmission errors and relayed by internet to the USCG Research and Development Center and the USCG Operations Systems Center (OSC), using a client application developed by the USCG residing on NDBC servers. Shore-side system processing and data flow is shown in Fig 2.

SBD packets containing AIS sentences are received from the DoD secure gateway at the NDAC. NDAC shore-side processes strip off the DoD gateway SBD packet wrapper, and then scan the packet for four data message types. The details of the SBD packet processing are shown in Fig 3.

The first data message type, indicated by a "$N" header, is an NDBC environmental data message. This message type is extracted from the SBD packets and sent by file transfer protocol (ftp) to the NDBC real-time data processing server where it ultimately finds its way to the National Weather Service Telecommunications Gateway (NWSTG), the Automated Weather Information Processing System (AWIPS), and the Global Telecommunications Gateway (GTS) for further dissemination.

The second message type, indicated by a "$R" header, is a message generated by the embedded buoy system in response to a Mobile-terminated command issued at the NDAC that reconfigures the AIS system on the buoy or requests maintenance information from the AIS system. These messages are transmitted by e-mail to NDBC operators.

The third data type, indicated by a "$GPGGA" header, is the buoy Global Positioning System (GPS) position, which is acquired once per hour by the GPS receiver embedded within the AIS receiver. Position is acquired only once per hour as a power saving measure and because the buoy is moored and normally does not drift more than approximately two nautical miles from its moored position.

The fourth data type, indicated by the header "!AIVDM," are the AIS VDMs. These messages contain vessel position and voyage-related data. Each of these AIS data messages, containing 160 to 1000 bits, within a given short burst data packet contains a checksum, which is validated by NDAC shore-side processing. As each sentence is validated, it is transmitted by IP socket to a client application developed by the USCG Research and Development Center that resides on the NDAC AIS server. This application also keeps an external IP socket alive to the USCG AIS servers using an embedded 'heartbeat' function in the client to maintain a persistent socket connection in the absence of any incoming data in order to ensure minimum latency of AIS data transmitted by the NDAC to the USCG. Data received by the USCG is then processed, archived and disseminated to other users and agencies.

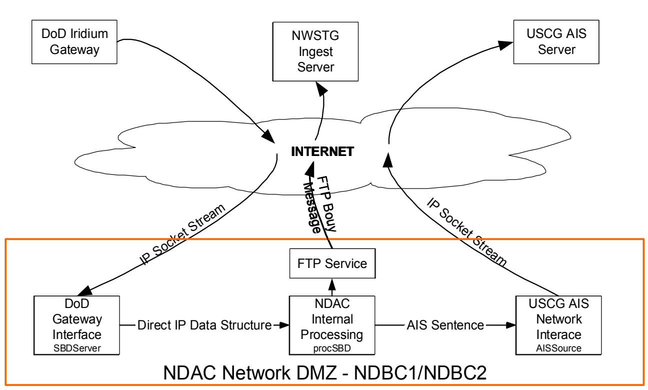

Figure 2. Shore-side Data Processing Flow

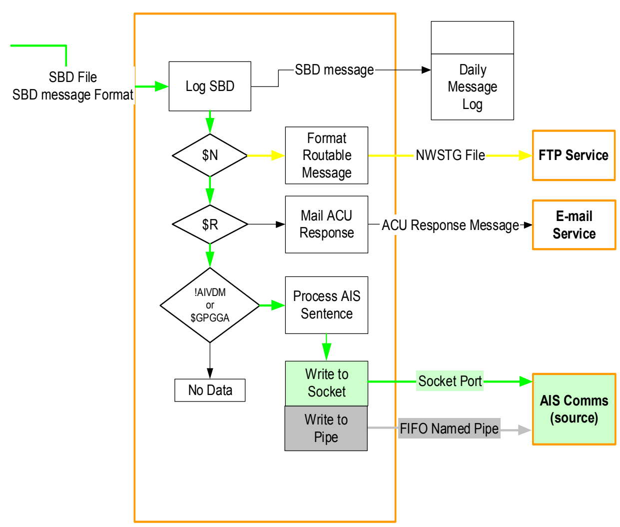

Figure 3. Short Burst Data Packet Processing

IV. System Testing

A. Test Conditions

The AIS system was tested in two stages. A proof-of-concept test was conducted for approximately 60 days in spring of 2005. This test involved a prototype system and AIS receiver integrated into a stand-alone package which included its own battery with sufficient capacity to operate the AIS receiver on a duty cycle of 5 minutes every 15 minutes for a period of approximately 60 days. The system was installed on four near-shore NDBC buoys to allow accessibility in the event of premature failures, and to coincide with shore-based AIS coverage for comparison of receipt of AIS messages. The buoy locations were: at the entrance to the Strait of Juan de Fuca offshore of Neah Bay, WA; 18 nautical miles west of San Francisco Bay; 40 nautical miles Southeast of Charleston, SC; and 30 nautical miles east of Nantucket, MA. Fig 4 shows a map of the test buoy locations.

Upon completion of this proof-of-concept testing, a second test of the AIS system was devised as a long-term evaluation of the system. The system deployed for long-term evaluation was installed on four NDBC buoys farther offshore in order to test the AIS receiver performance in the very low radio frequency noise environment of deep ocean buoys to determine if system range improvements were possible in this low noise environment. The buoy locations were 88 nautical miles south of Kodiak, AK, 275 nautical miles west of Coos Bay, OR, 200 nautical miles east of Cape May, NJ, and 64 nautical miles east of Virginia Beach, VA.

The system deployed for this long-term evaluation included some firmware changes and additions based on lessons learned from the proof-of-concept test. These system design changes include: some re-design of the AIS receiver by the manufacturer to reduce its power consumption significantly and to allow remote control of its embedded GPS receiver for additional power savings; operate the AIS receiver continuously in order that no vessels in the detection range are missed as a result of the AIS receiver being turned off; interface the AIS system to the NDBC buoy renewable power system to allow operation beyond a 60-day period; and embed NDBC environmental data with the AIS data and transmit it with the AIS data by IRIDIUM SBD packets to eliminate the need for a GOES data transmitter normally used on NDBC buoys as a further power savings measure. The result was a system with better vessel monitoring capability that used significantly less power than the proof-of-concept system. The substantial reduction of power consumption allowed system re-programming to transmit AIS data by SBD packets every ten minutes rather than every fifteen minutes increasing the data volume available to the USCG.

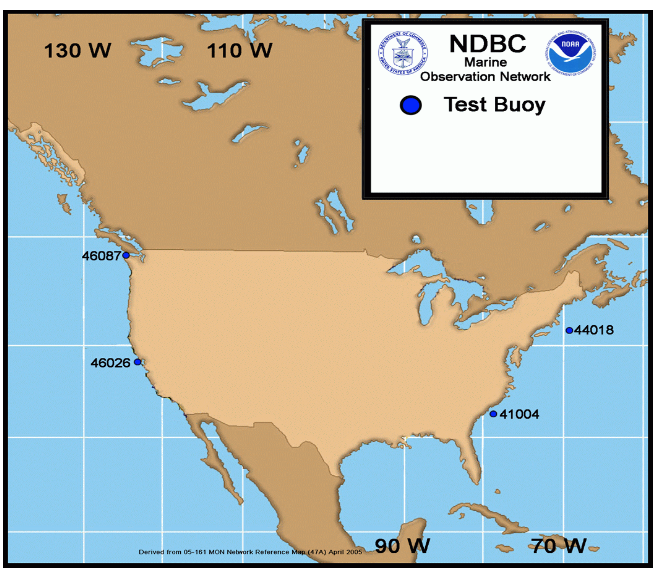

Figure 4. Buoy Locations for Proof-of-Concept Test

B Test Results

Test results of the 60-day proof of concept demonstrated that all system requirements were achieved. Typical range from the buoys at which vessels were detected was 25 nautical miles, near the theoretical limit for marine band VHF transmissions for a buoy antenna height of 20 feet above the ocean surface and an assumed vessel antenna height of approximately 100 feet above the ocean surface. Under conditions of electromagnetic ducting or during weather phenomenon conducive to troposphere scatter, vessels were detected as far as 400 nautical miles from the buoy.

System data latency was restricted by the minimum time required for a SBD transmission to be completed, which was approximately 25 to 30 seconds for packet sizes at the maximum 1960 bytes for SBD, so the minimum possible time between arrival of an AIS message at the buoy to its arrival at NDBC was 25 to 30 seconds. Worst case latency was as long as 5 minutes, 30 seconds which can occur when an AIS sentence is received at the buoy at the beginning of the 5 minute acquisition period and it is the only AIS message received from that vessel during the entire acquisition period, i.e., a vessel that makes a grazing pass at the limit of the buoy AIS radio range. Observed latencies were nearly always under two minutes with typical latencies on the order of 40 seconds. Typical internet latencies from the DoD gateway SBD server to the NDAC server, or from NDAC server to the USCG AIS server were under one second for each transmission leg.

IRIDIUM SBD transmission reliability during the test period exceeded 98 percent reception of the total SBD message attempts from all buoys. The IRIDIUM gateway downlink command and control signal operates in the Ka-band of the spectrum. This frequency band is subject to rain fade and thus there is a possibility of missed transmissions due to the occurrence of rain fade, an event which can occur frequently in Hawaii, the location of the DoD gateway. Given the frequency of potential rain fade events at this location, 98 percent successful transmission of all SBD messages attempted exceeded expectations.

The embedded buoy system power consumption for the proof-of-concept system was determined as 2.12 Ampere-hours/day for an AIS receiver duty cycle of 5 minutes on every 15 minutes.

At the time of publication of this paper, two of the four systems for long-term testing were deployed. The locations of the two deployed systems locations were 88 nautical miles south of Kodiak, AK and 64 nautical miles east of Virginia Beach, VA.

Typical maximum ranges for detected vessels at these buoys were 40 nautical miles from the buoys. Both buoys are 6-meter nomad buoys with AIS VHF antenna heights at 20 feet above the ocean surface. Preliminary indications show an improvement of detection range on the order of 60% for the same buoy antenna heights used in proof-of-concept testing. This is believed to be a result primarily of the much lower radio frequency noise environment of the deep ocean buoys, which are much farther from land-based sources of radio interference. There was one instance of apparent electromagnetic ducting during the test period where barge traffic was detected from Memphis, TN, at the Virginia Beach, VA buoy, which is more than 700 nautical miles from the buoy, although this was an uncommon occurrence.

System data latency was similar to that seen in the proof-of-concept tests, however in high traffic areas, more than one SBD message is required to send back all the data collected. This is a result not only of increased vessel traffic, but of the AIS receiver continuously monitoring the AIS frequencies, rather than only 5 minutes every 15 minutes. The increased monitoring time results in collection of data that may have been missed with the proof-of-concept system that operated with reduced AIS receiver on time. Each additional SBD packet adds 25 to 30 seconds to data latency.

IRIDIUM SBD transmission reliability to date has exceeded 98% on the station south of Kodiak, AK and 99% on the station east of Virginia Beach, VA.

The buoy embedded system power consumption was measured pre-deployment and found to be 2.95 Ampere-hours/day for an AIS receiver on continuously, with SBD transmissions every 10 minutes rather than every 15 minutes as with the proof-of-concept system, a substantial decrease in system power consumption.

V. Conclusion

The development and testing of a buoy-based AIS monitoring system, as described, demonstrated the feasibility of extended offshore monitoring of vessel traffic on the AIS frequencies from buoys. This system can extend coverage of the present capability of shore-based AIS monitoring stations, which are subject to significantly more radio frequency interference from land-based transmitters than is AIS receiving equipment on offshore buoys. System proof-of-concept was successfully demonstrated with a limited power, limited monitoring time system. Extended testing with a system farther offshore with continuous monitoring of AIS frequencies and long-term, renewable power from the buoy showed initial results indicating a potential increase in typical detection range of 60%, which is believed to be primarily a result of the decreased radio frequency noise environment on buoys farther offshore. This system has demonstrated the ability to extend AIS monitoring coverage using remote, unattended platforms with low-power AIS monitoring systems.

Future plans for AIS on NDBC buoys include potential expansion of the system to more buoys offshore, addition of the AIS package to buoys deployed for hurricane tracking and incorporation of additional sensors and AIS data processing. It is possible that AIS data may be transmitted from buoys, allowing weather and other safety information for mariners to be sent automatically via AIS. With the potential development of these extended AIS messages, it may also be feasible to receive weather observations from vessels automatically via AIS.

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